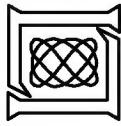


LINEAR System Performance Analysis

Jenifer Brinker Evans

Space Control Conference

3-5 April 2001

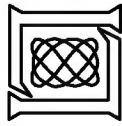


REPORT DOCUMENTATION PAGE

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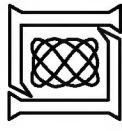
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- Background
- Performance Analysis -- The big picture
- Performance Analysis -- The details
- Future work

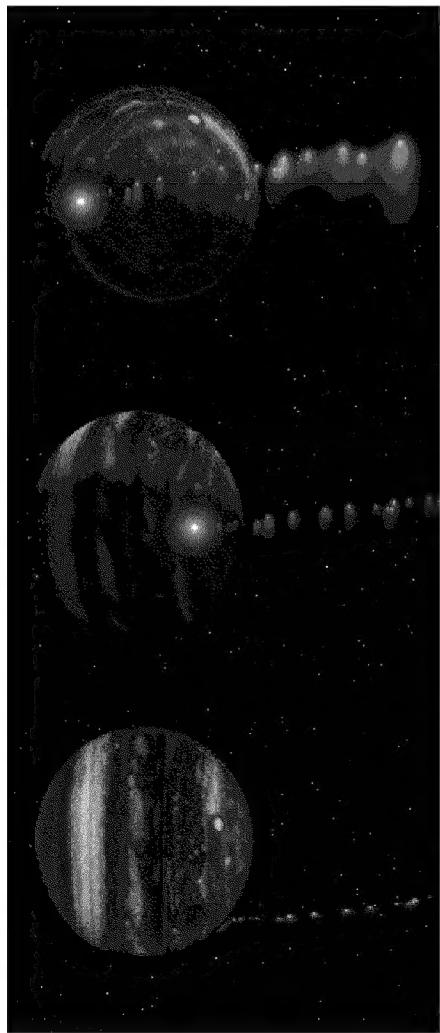
Acknowledgements:

Lexington: Ron Sayer, Scott Stuart, Herb Vigg

New Mexico: Frank Shelley, Eric Pearce, Peter Trujillo, and the observers!



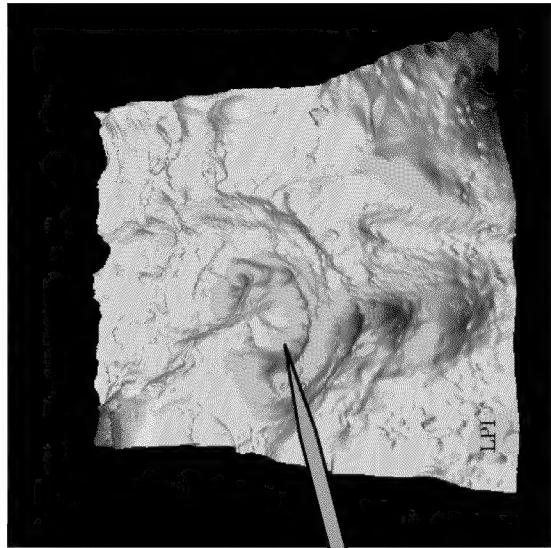
Impacts Happen



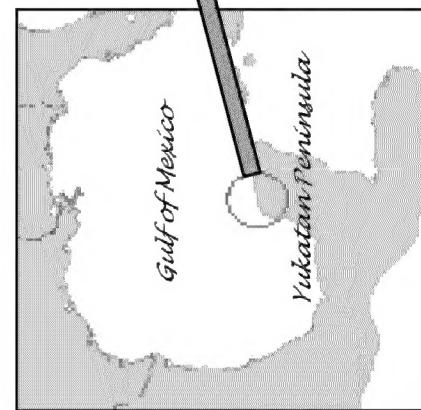
Shoemaker-Levy 9 and Jupiter (1994)



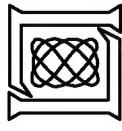
Meteor Crater, Arizona
(~50,000 years ago)



Chicxulub, Mexico
(responsible for K-T extinctions?)
MIT Lincoln Laboratory



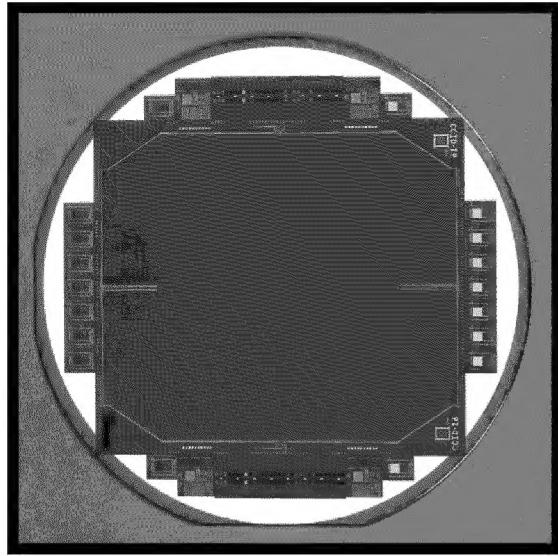
Tunguska, Siberia (1908)



Lincoln Near Earth Asteroid Research (LINEAR)

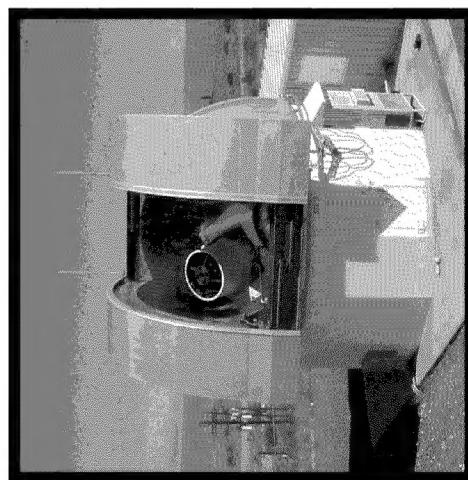


Experimental Test Site (ETS), Socorro, NM



Lincoln Laboratory developed CCD

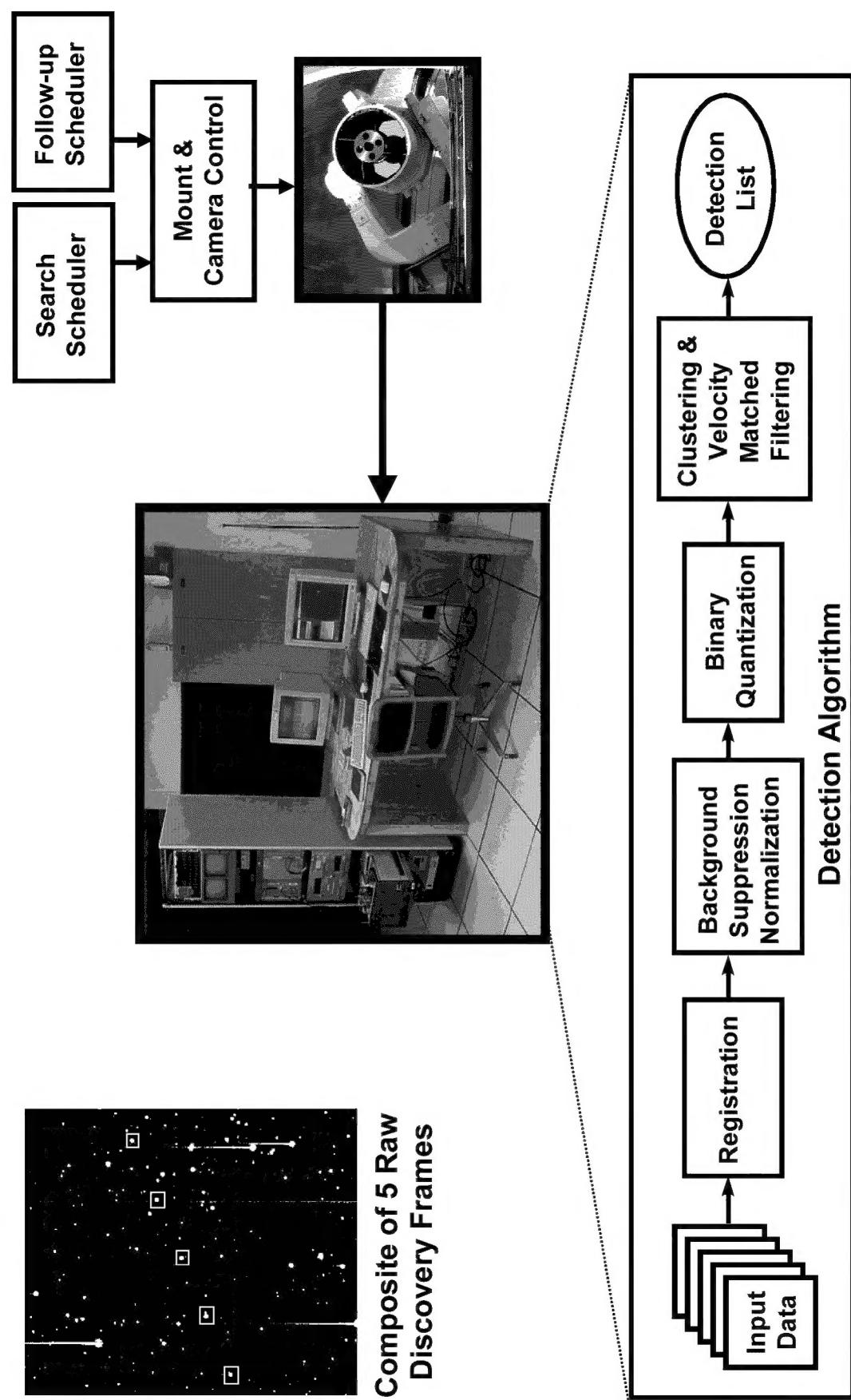
- 2560 x 1960 pixels, 2.25 arcsec per pixel
- Very low readout noise (few electrons per pixel)
- Back illuminated
- Peak quantum efficiency > 95%
- Solar weighted quantum efficiency = 65%
- Frame transfer to frame buffer in milliseconds

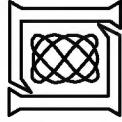


GTS-1 and GTS-2 (GEODSS) Telescopes



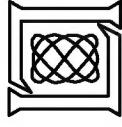
LINEAR Detection System





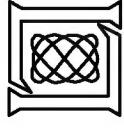
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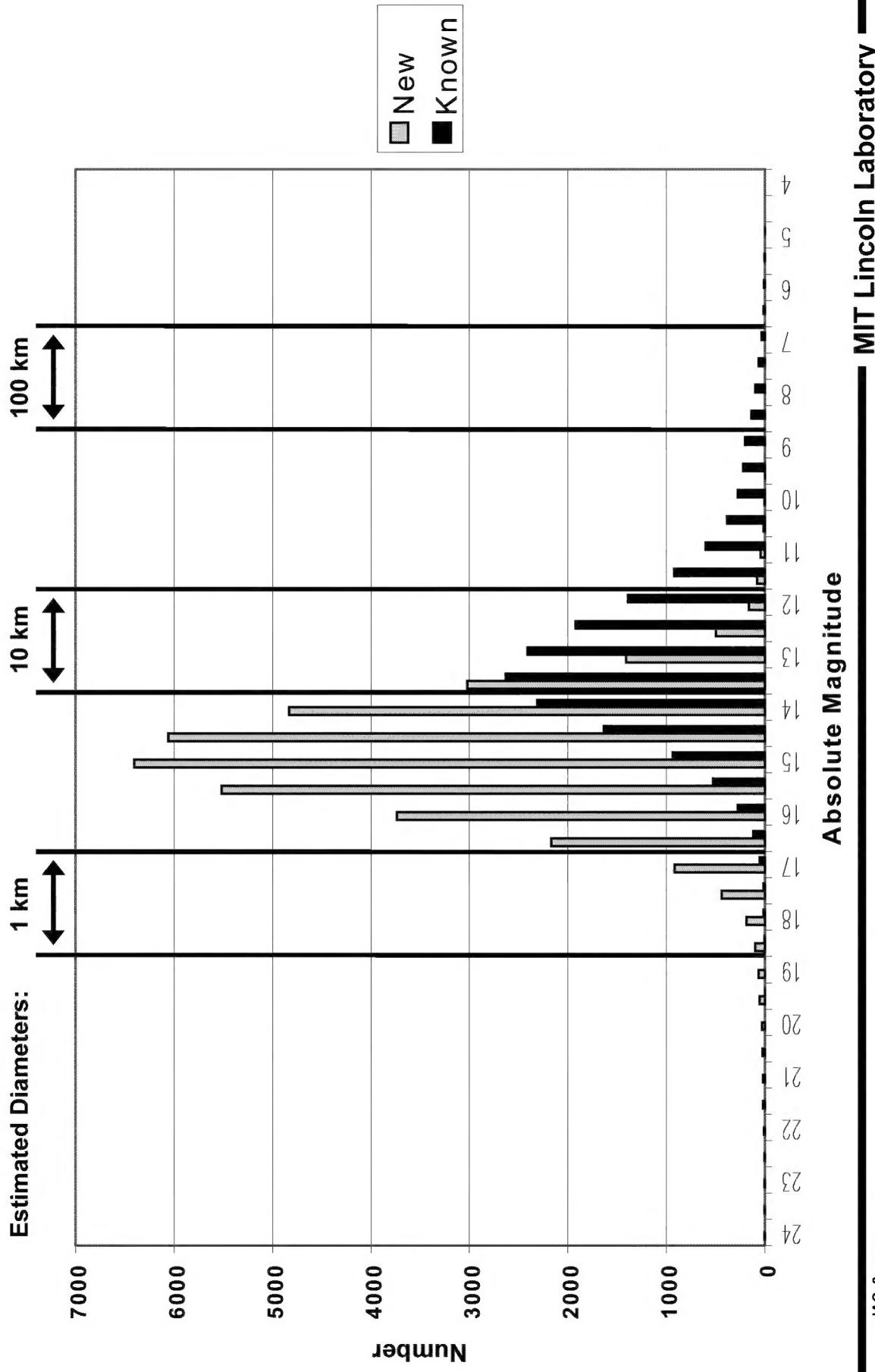


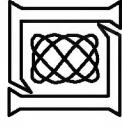
LINEAR Observations and Discoveries

Lunar Dark Period	Obs sent to MPC	NEO Discoveries	Comet Discoveries	Total Discoveries
9/00	211,014	39	5	9,667
10/00	340,743	22	1	3,827
11/00	229,071	36	1	1,433
12/00	234,978	14	0	Coming soon
1/01	231,377	23	3	Coming soon
2/01	227,916	19	2	Coming soon
Totals 2001	459,293	42	5	Coming soon
Totals 2000	2,268,676	258	17	44,953+
Totals 1999	1,301,999	161	22	28,922
Totals 1998	760,893	135	16	18,149
Totals pre 1998	83,762	19	0	2,123
Grand Totals	4,644,401	614	60	Coming soon

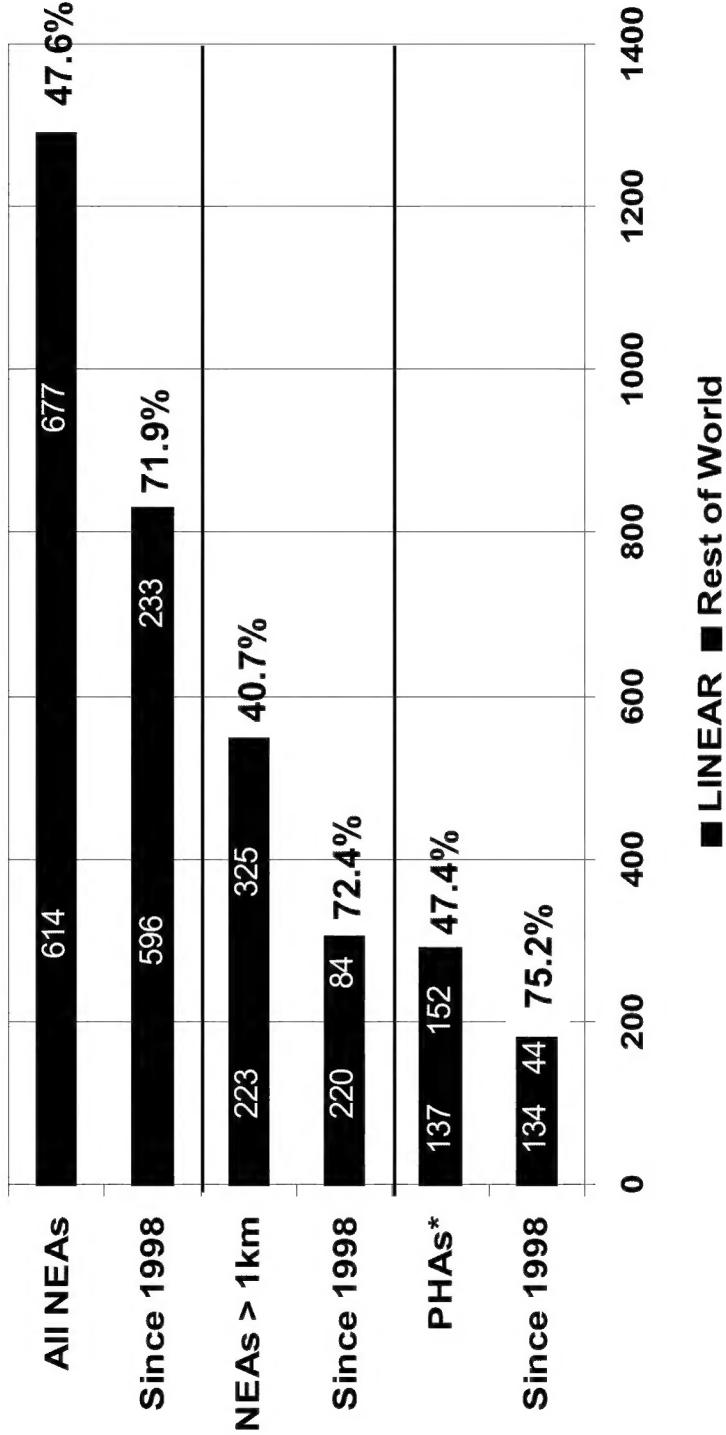


Absolute Magnitudes of Asteroids Detected by LINEAR



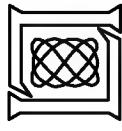


LINEAR's Share of Near Earth Asteroid (NEA) Discoveries



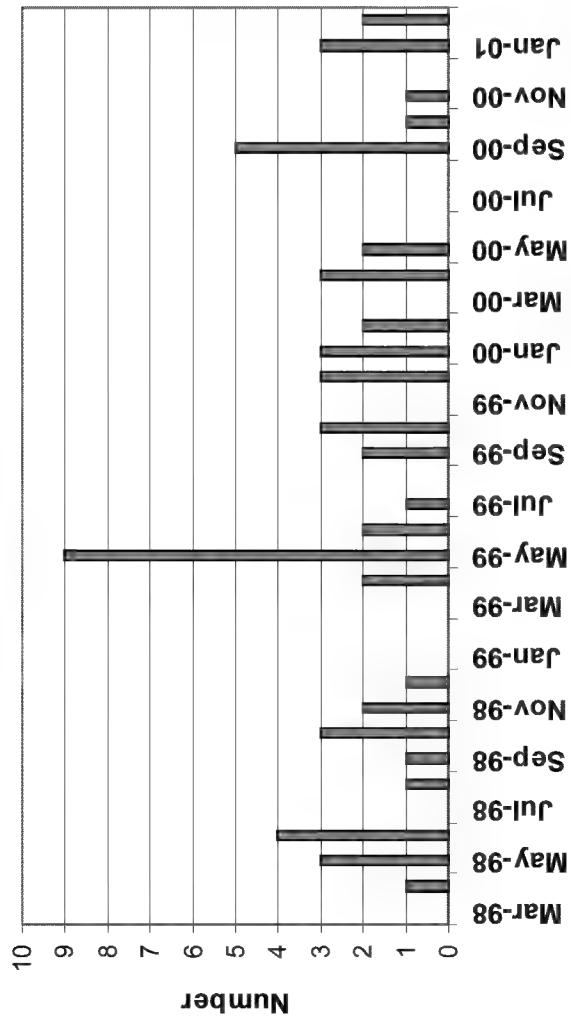
- First NEA discovered in 1898
- LINEAR has discovered 60 comets

*PHA: Potentially Hazardous Asteroid, defined by Minor Planet Center.

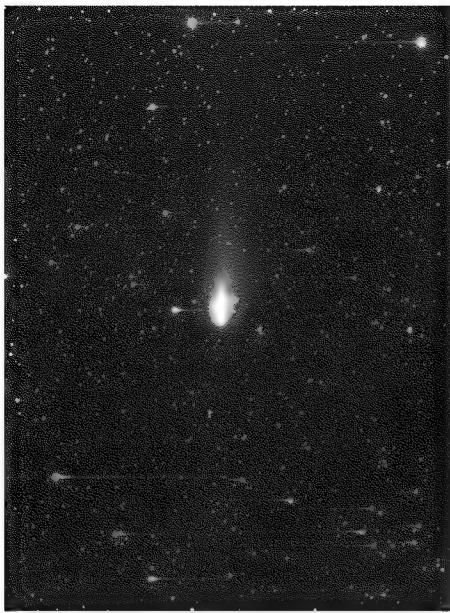


LINEAR Comet Discoveries

60 Comet Discoveries



C/1999 S4 LINEAR

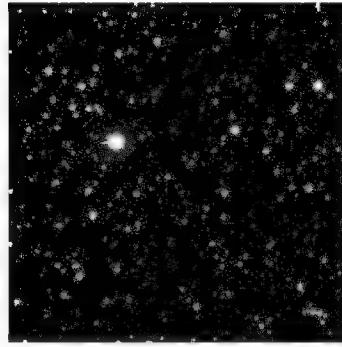


Discovered 27 Sept 1999

This image from 25 June 2000
Closest approach 23 July 2000 with

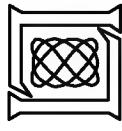
peak magnitude ~6.5.

Exploded and 'vanished' 26 July.



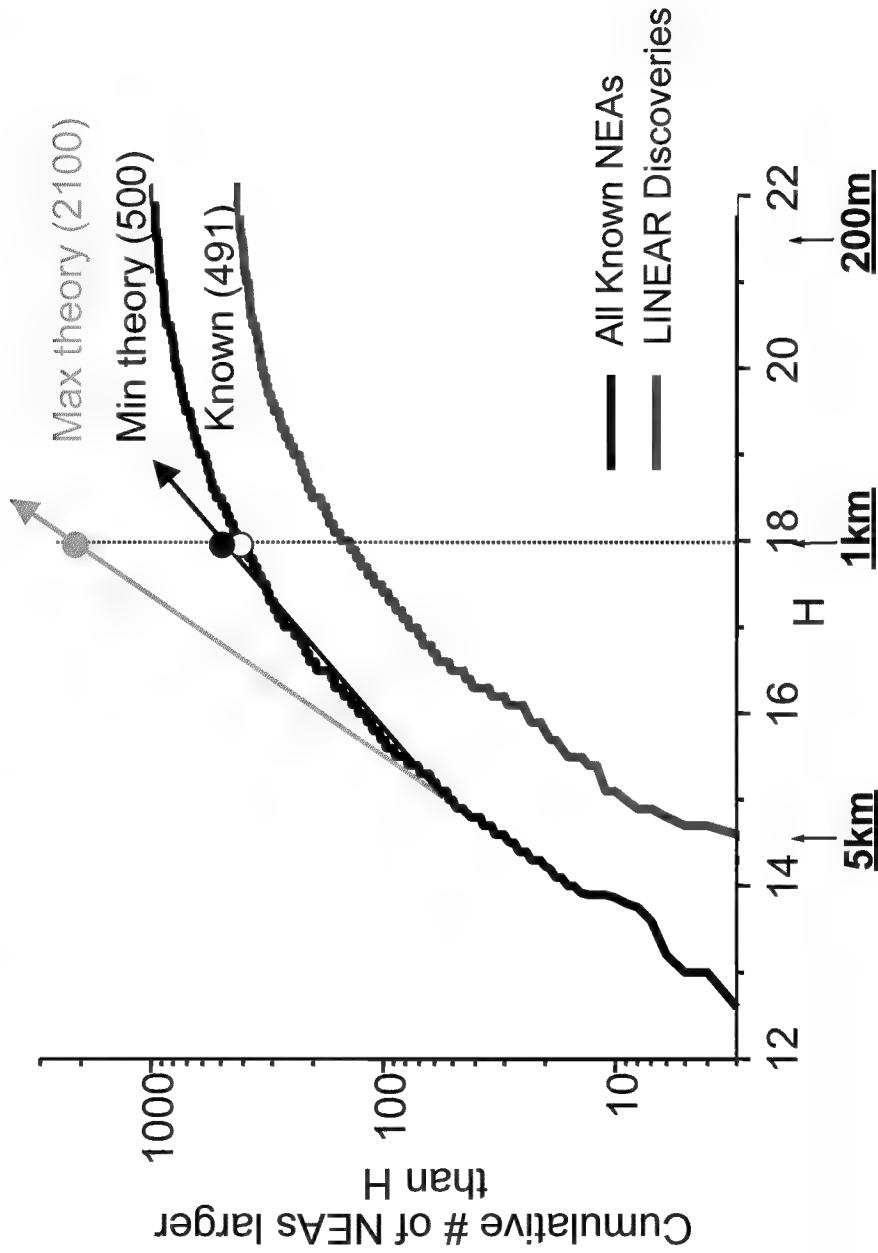
C/2000 WM1 LINEAR

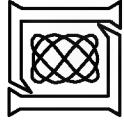
the 'Christmas Comet'
Discovered 16 Nov 2000
Closest approach 22 Jan 2002
Likely 3rd-5th magnitude



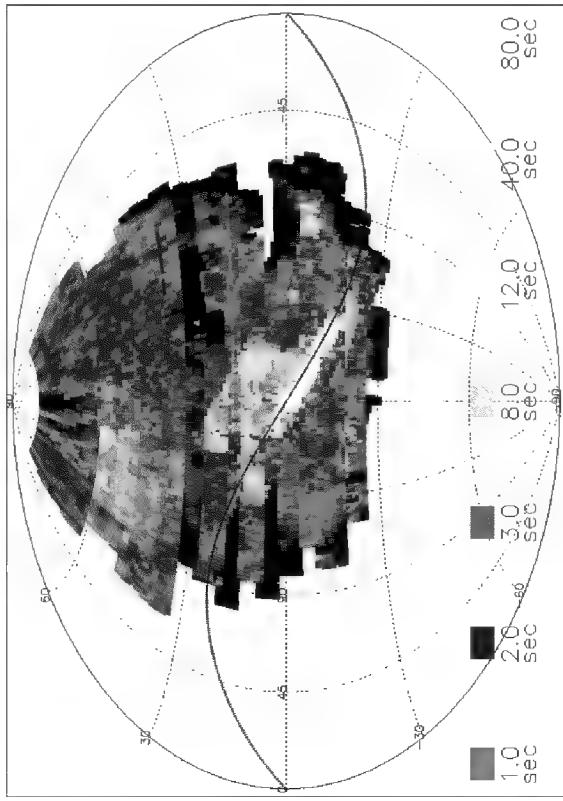
NEA Population and NASA's Goal

NASA's Goal:
Find 90% of NEAs greater than 1 km diameter by 2008

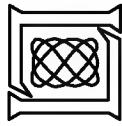




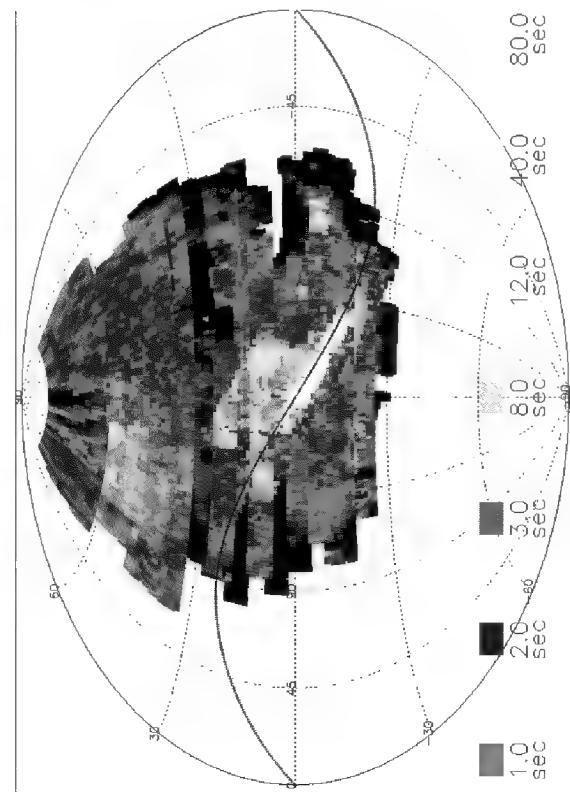
LINEAR Sky Coverage



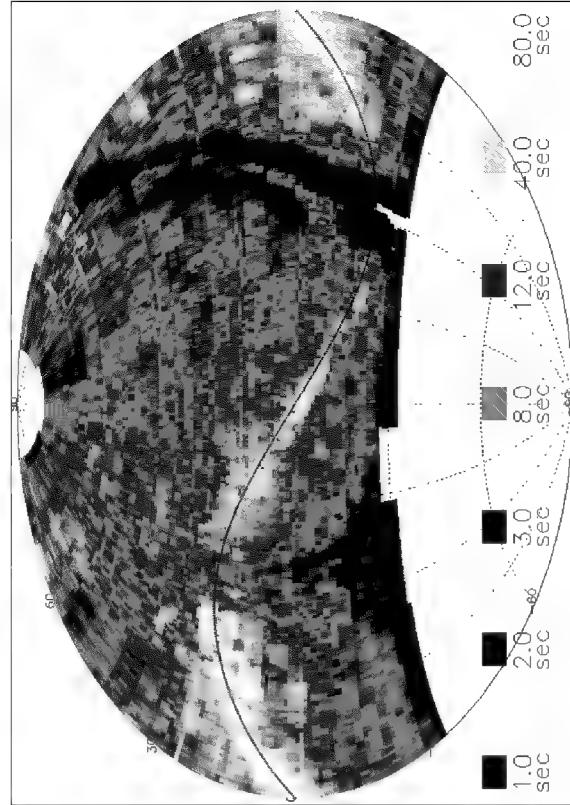
**April 2000
2 telescopes
Approximately 17,000 sq degrees**



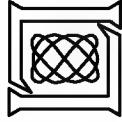
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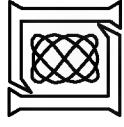


Sept 1999 – Sept 2000
2 telescopes since February 2000

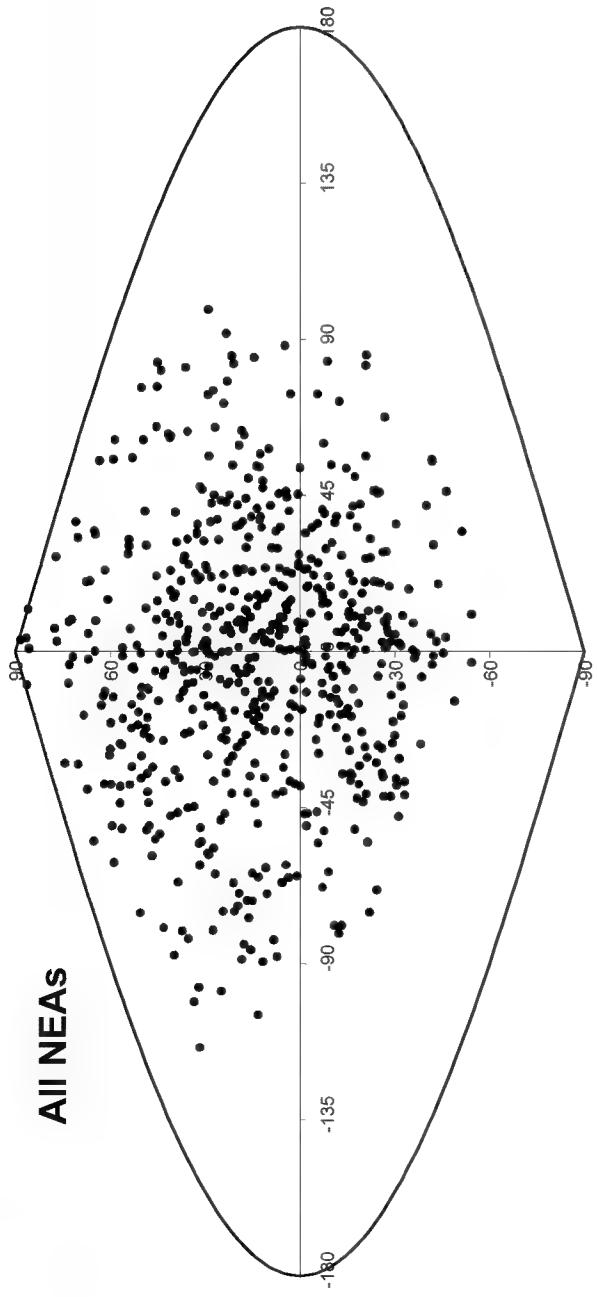


Outline

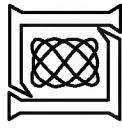
- **Background**
- **Performance Analysis -- The big picture**
- **Performance Analysis -- The details**
 - **Search pattern effectiveness**
 - **Depth of search**
 - **Population estimate**
- **Future work**



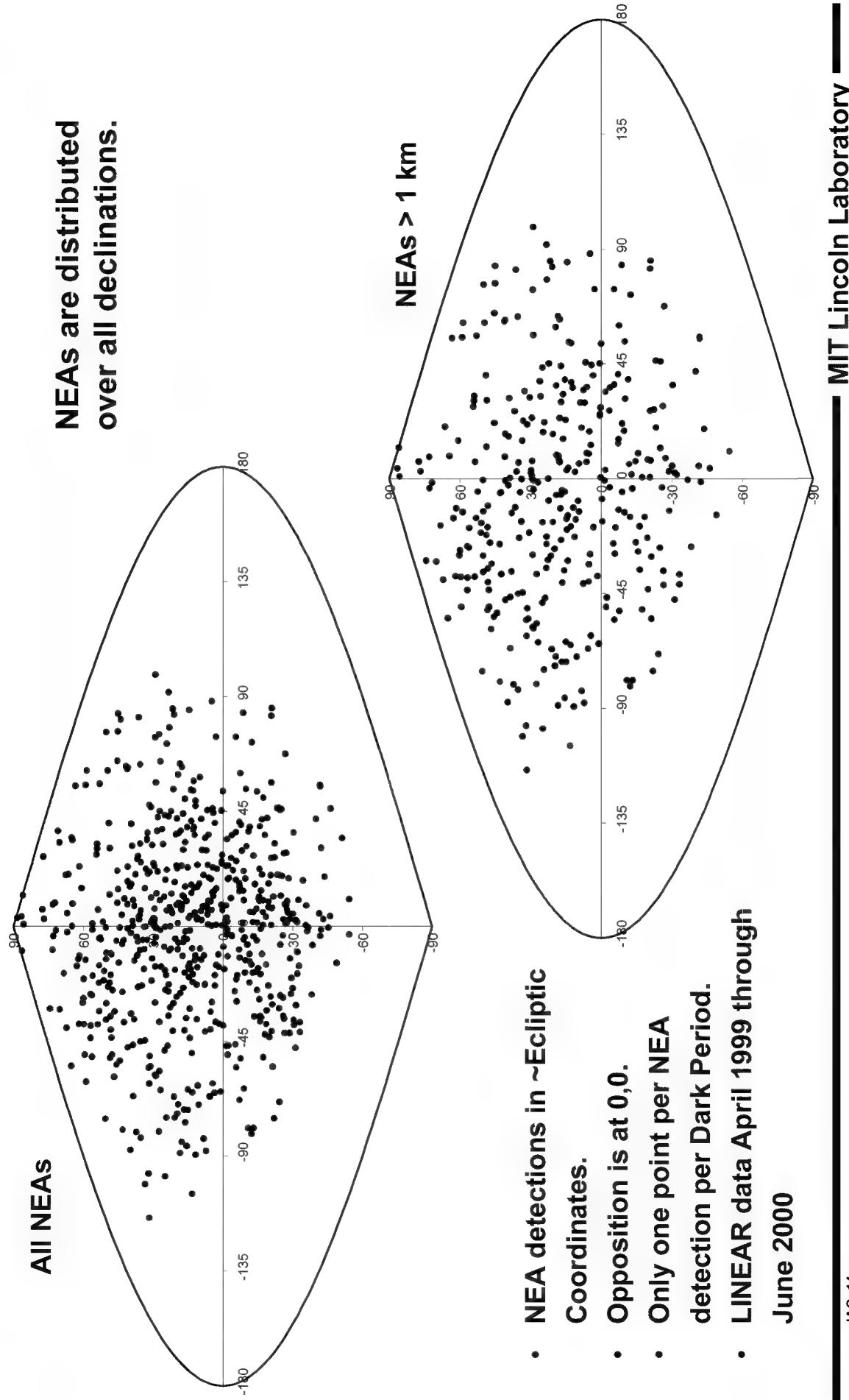
Distribution of NEA Detections

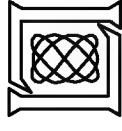


- NEA detections in ~Ecliptic Coordinates.
- Opposition is at 0,0.
- Only one point per NEA detection per Dark Period.
- LINEAR data April 1999 through June 2000



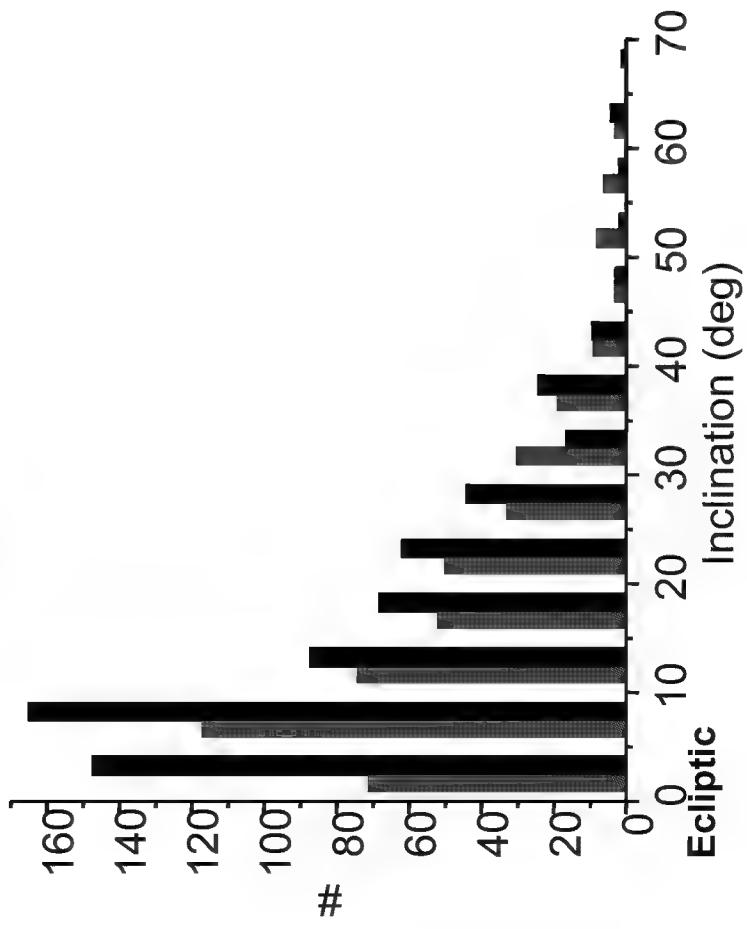
Distribution of NEA Detections





Distribution by Inclination

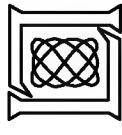
All known NEAs
binned by inclination



Discoverer

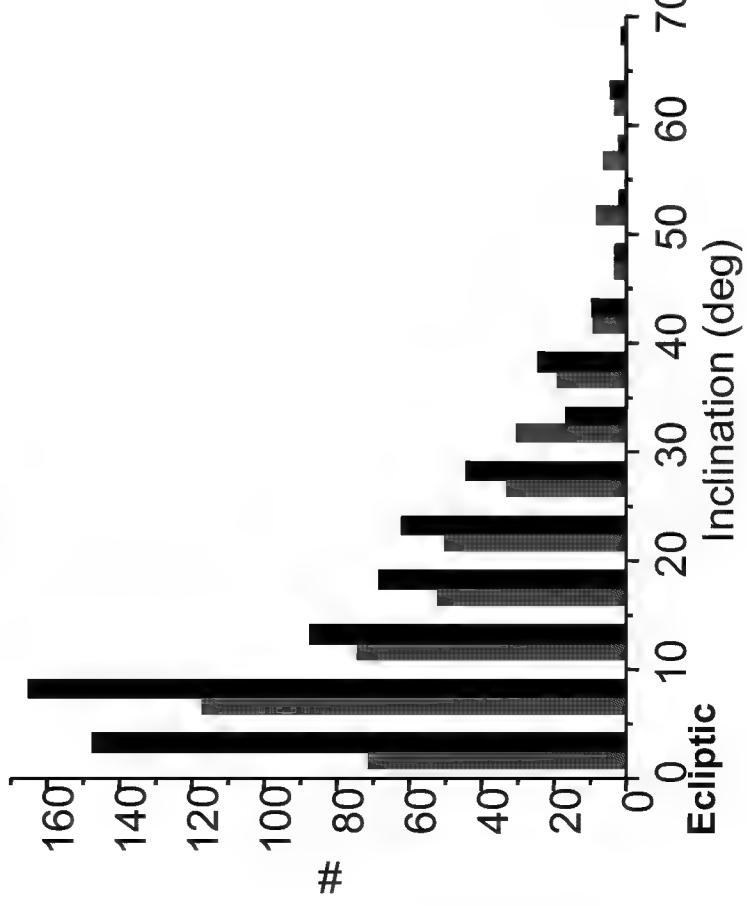
LINEAR

Non-LINEAR

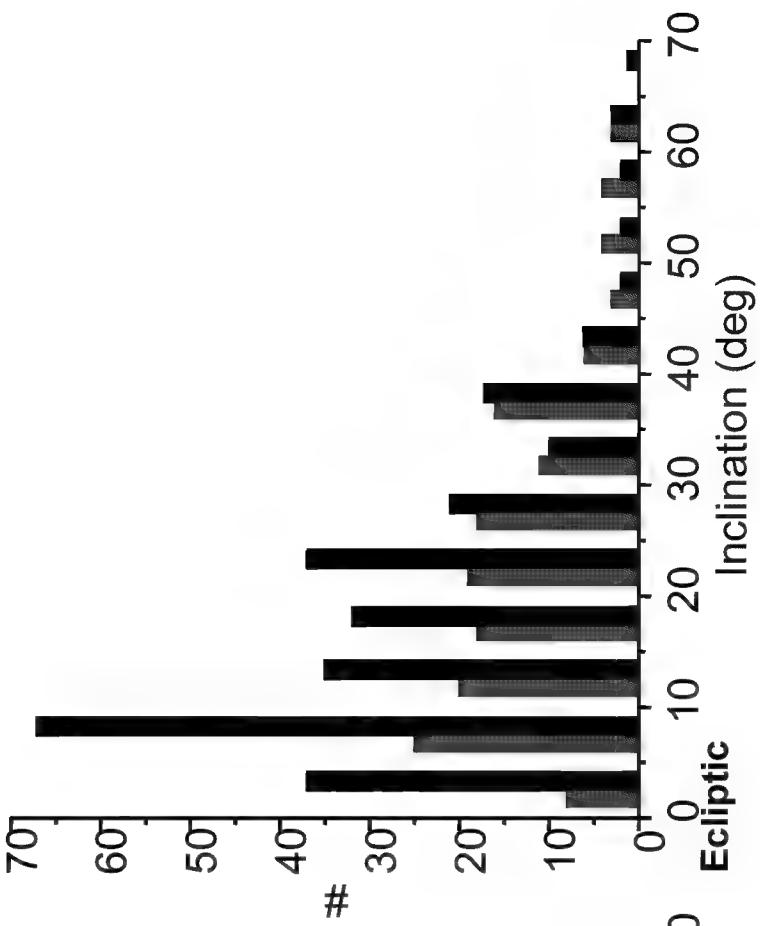


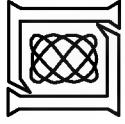
Distribution by Inclination

All known NEAs
binned by inclination

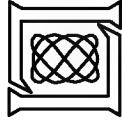


All known large NEAs
binned by inclination



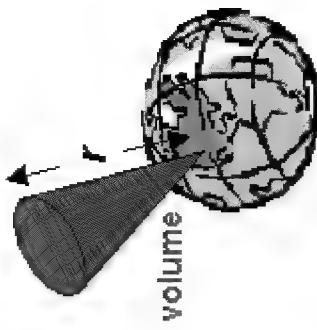


Depth of Search



Determining Search Volume

- Limiting magnitude can be translated to volume searched for an object of a known size/brightness. Solve for r.



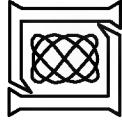
$$V_L - H = 5 \log(r/\Delta) - 2.5 \log[(1-G)\Phi_1 + G\Phi_2]$$

with

$$\Phi_1 = \exp[-3.33(\tan \frac{\beta}{2})^{0.63}], \quad \Phi_2 = \exp[-1.87(\tan \frac{\beta}{2})^{1.22}]$$

$$G = 0.15, \quad H = 18.0$$

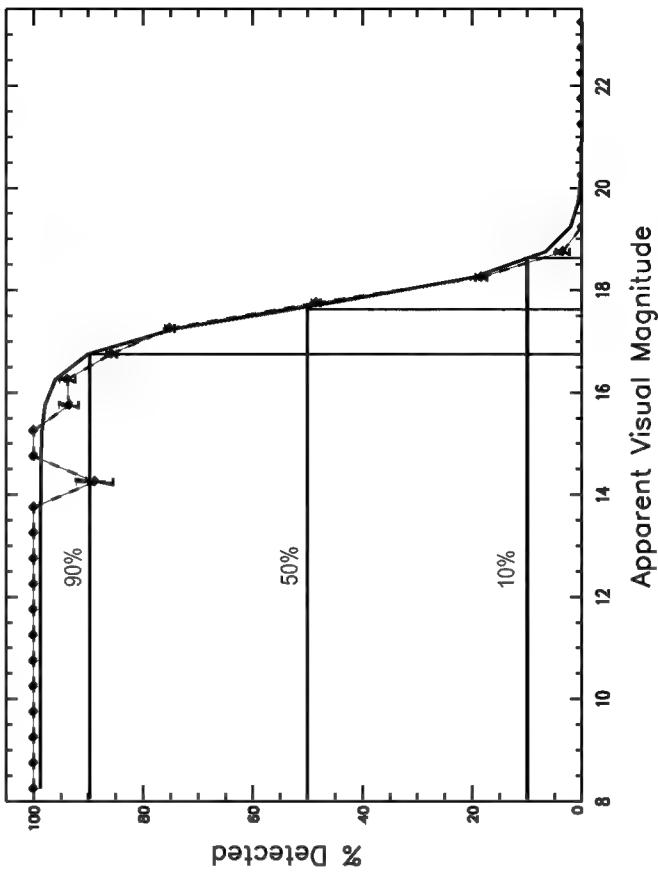
- Volume searched can be used as common metric for various search programs.
- Various search programs have begun discussing coordination to optimize overall search.
 - All programs need to characterize system capabilities.

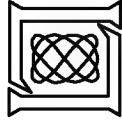


Limiting Magnitude Determination

- Limiting visual magnitude affected by
 - Atmospheric conditions
 - Night sky brightness
 - Systematic losses
- Detection efficiency curve generation
 - Numbered and multi-opposition asteroids with known magnitudes.
 - Propagate asteroids to night of search
 - Compute percent detected in each bin
- Curve generated for each night

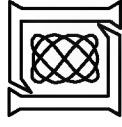
**Sample detection efficiency curve
for a single night's search**





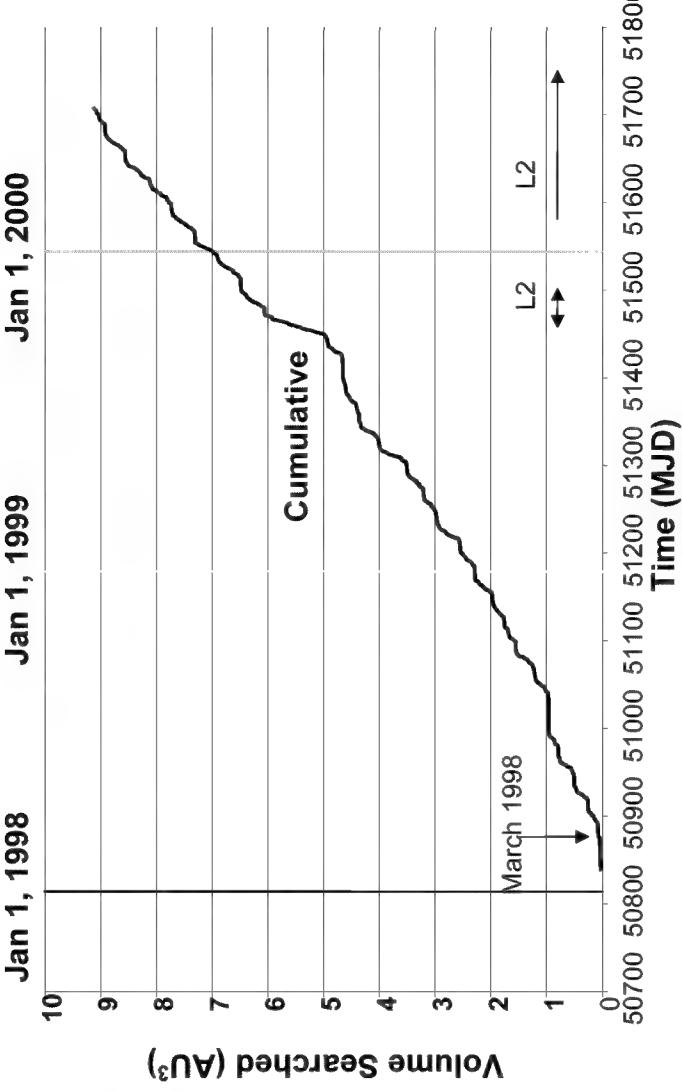
Volume Searched by LINEAR

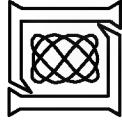
- LINEAR measures SNR6 value for every field searched.
 - SNR6 is known magnitude of a star with measured signal-to-noise equal to 6.
- SNR6 values agree with nightly based 50% cutoff detection efficiency value.
- Limiting magnitude values can be computed on a field by field basis.



Volume Searched by LINEAR

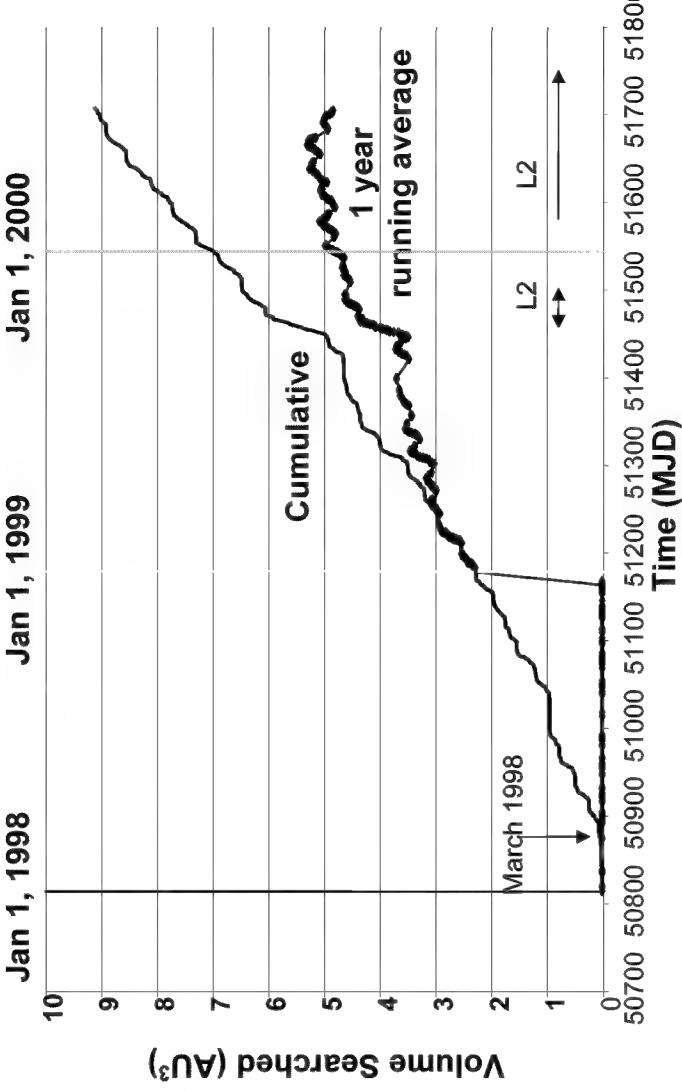
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 - Limiting magnitude values can be computed on a field by field basis.
- Calculate volume searched in au^3

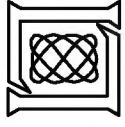




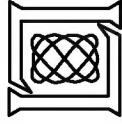
Volume Searched by LINEAR

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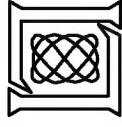


Population Estimate



Population Estimate for Large NEAs

- Topic of great interest
 - 2100 by Morrison, 1992
 - 750 by Rabinowicz, 2000
 - 900 by Bottke, 2000
- Typical method: 10's of detections and many Monte Carlo simulations
- New estimate by Scott Stuart, Lincoln Lab Scholar
 - Using 100's of detections by LINEAR
 - Using new inclination distribution
 - Using LINEAR detection efficiency information
 - Using Bayesian analysis



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1100 +/- 100

Summary and Future Work

- LINEAR contributing 72% of NEA discoveries since 3/98
 - Approaching 50% of all NEA discoveries ever.
 - Searching 15,000 – 17,000 square degrees/month
 - LINEAR is contributing significantly to the NASA goal
- Continue system characterization to benefit coordination of various search programs and for self-improvement.
 - Generate detection efficiency curves for every night.
 - Analyze limiting magnitudes as a function of integration times and search patterns.
 - Experiment with and analyze various search patterns.
- Continue characterizing known NEO population.